# INVESTIGATION OF LARGE-AREA HIGH-CURRENT MICROCHANNEL PLATE DETECTORS FOR TIME-OF-FLIGHT MASS SPECTROMETRY

FINAL REPORT
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# I. SUMMARY

The purpose of this study was to investigate MCPs to be used in the TIDE time-of-flight (TOF) mass spectrometer, including the development of criteria for their selection, test, and burn-in.

# II. RESULTS

A. High current MCPs were studied early in this project and were rejected due to the large strip current that they required and the resulting large demands on instrument power. A typical single MCP presents a resistive load of ~$10^8$ ohms so that the total resistive load of seven MCP Z-stacks in parallel (the TIDE case) dissipates ~200 mW of load power. The high current MCP version would approach ~1.0 W of dissipated power and was judged unacceptable for the final TIDE design in which power had grown in other areas as well.

B. Similarly, our initial plans to use custom-designed MCPs that were fabricated by laser cutting specially shaped MCPs from oversize stock MCPs, proved to be difficult and were abandoned. The laser cutting method was judged impractical because the stock MCPs (rectangular-shaped 40 X 50 mm plates) had solid borders of glass that, when cut through by the laser, released stresses within the MCP capillary array. These stresses caused the plates to crack. Sometimes the crack would appear with a delay of 1-2 days, making quality control of the process difficult.

In the end, we decided to use standard 25.0 mm OD MCPs procured from Mullard Electronics in the UK. In order to use these plates with their circular cross-section and reduced collecting areas (compared to custom-cut MCPs), we developed a method for focussing incident ions, and the resulting foil-generated secondary electrons, in the azimuthal direction, i.e. in the direction that would squeeze the ion and electron trajectories onto the stop and start MCPs respectively. In this way, little efficiency would be lost compared to the custom plates. Both 2½-dimensional ray tracing and subsequent prototype sensor tests suggested that this method works.

C. After Task B was completed (corresponding to Tasks 2 and 3 of the original proposal), we proceeded to design a mechanically efficient MCP mount for both start and stop detectors. Our goal was to make the mountings rugged but serviceable once they were in place on the printed circuit-type board used to mount both the MCPs and their preamps. We believe we have succeeded in this regard, however, vibration tests of the TIDE sensor will be required to confirm the design.

D. We designed and fabricated an MCP bake-out and burn-in facility. The facility is based on $^{53}$Ni β-sources which excite the MCPs at rates that are controlled using an aperture wheel, and vary from ~100cts/s up to ~40,000 cts/s. Both burn-in and bake-out facilities are UHV systems pumped cryogenically and monitored continuously with a pressure gage and residual gas analyzer system. Each facility accommodates up to 4 MCP stacks. The facility has been used to burn-in all 42 MCPs (plus spares) presently mounted in the TIDE proto-flight unit. (Attached to this report are procedures for bake-out, burn-in, and life tests of TIDE MCPs together with a discussion of the basis for these procedures.)

E. Figure 1 shows a typical pulse height distribution for a Galileo 25mm OD MCP taken in the TIDE facility following a bake-out and burn-in procedure. The modal gain of this particular MCP stack is $5.8 \times 10^6$ at -2600V with FWHM = 43%.

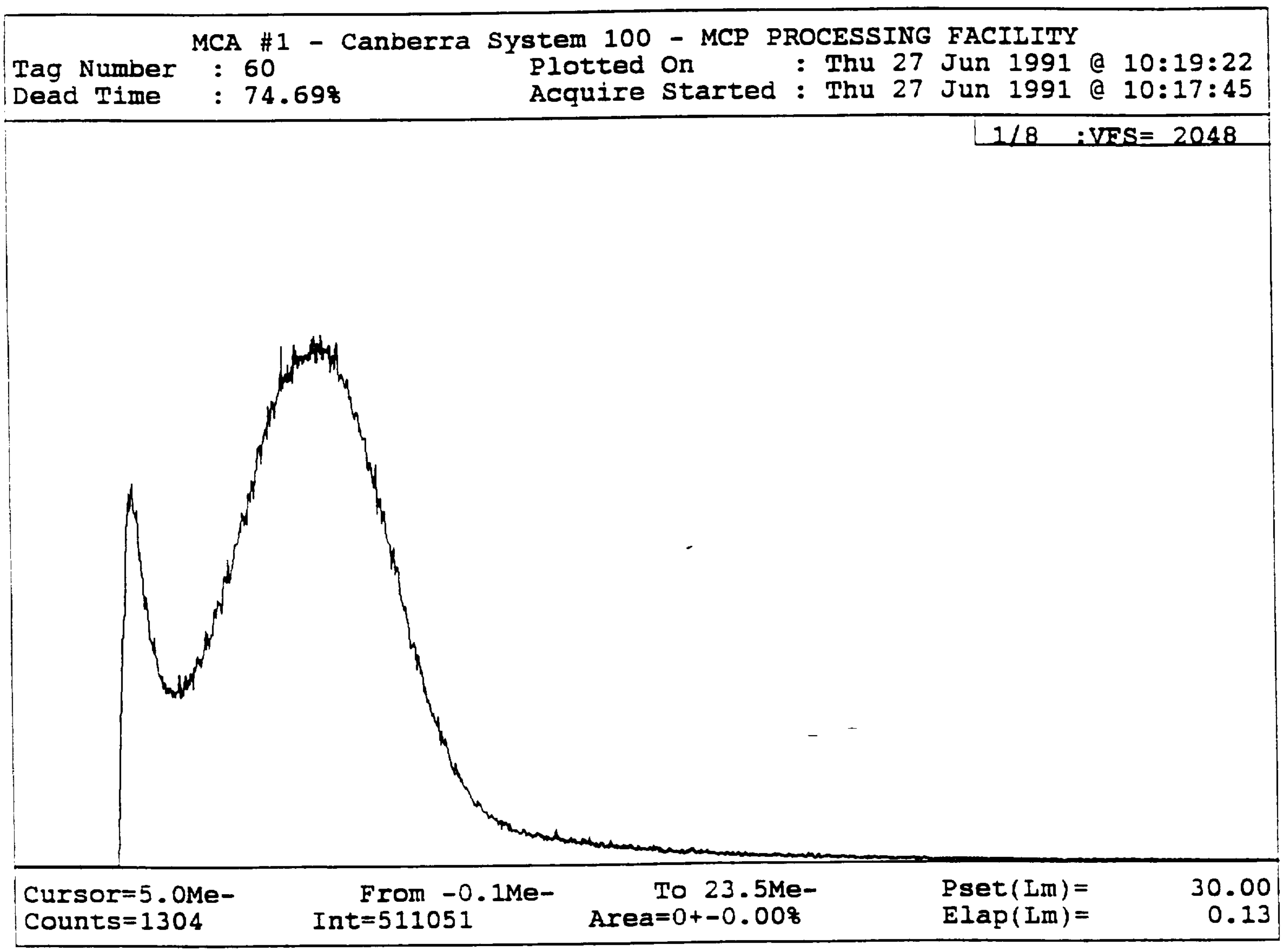


Figure 1

# MCP Bake-out, Burn-in and Lifetime Test Procedures for TIDE/Polar/GGS

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Prepared by D. T. Young, SwRI

## 1. Background

It is assumed that the reader is familiar with microchannelplates (MCPs) and their operation. The purpose of this note is to discuss MCP burn-in and life-time and give procedures for burn-in and lifetime tests for the TIDE/Polar instrument. For the purpose of collecting this information and procedures I assume that the surface properties of MCPs and channeltrons (CEMs) are identical and require identical treatment. (New "long-life" glass materials may be an exception here, but all TIDE MCPs will be nearly identical due to HV power constraints.) The primary difference between them is the division of the MCP multiplier structure into several discrete plates (a "Z-stack" of 3 individual plates for TIDE) each of which provides a operational maximum gain $\sim$ 300 so that the total TIDE gain is $\sim 300^3 = 2.7 \times 10^7$. Thus the first plate in the stack sees the incoming ion flux but outputs only $\sim$ 300 electrons per incident particle. The second stage sees $\sim$ 300 input electrons and has an output of $\sim 9 \times 10^4$ electrons, with the final stage having an output $\sim 3 \times 10^7$ electrons. (Note, however, that some of this multiplication comes from the spread of the electron cloud through the MCPs.) This suggests that the MCPs should be burned-in as a stack and should be maintained in a particular ordering throughout all phases of test and flight since each plate will undergo a different degree of burn-in depending on its location in the stack. (Note that burn-in of one plate at a time is impractical for this reason.) There is some concern that we should rotate the order of individual MCPs in the stack; however, this is difficult to do in practice and, secondly, by appeal to the analogy with CEMs, it is not clear that rotation of order is needed.

Microchannelplates and CEMs are made from special lead oxide glass which is rendered semiconducting by means of partial reduction of the lead oxide through baking of the finished product in a hydrogen atmosphere. The latter is a diffusive process, so the resulting semiconducting layer is quite thin (few $\mu$m). MCPs are known to be susceptible to long term degradation which may take the form of catastrophic loss in MCP efficiency due to a loss in gain. Monitoring of MCP gain therefore provides a monitor of degradation. There is no published description of the surface phenomena involved in the degradation process; however, the following explanation (due to H. Rosenbauer) provides a reasonable basis for our procedures.

An MCP works by multiplying an electron cascade along its semiconducting walls. Each "stage" must have a gain of $\sim$ 1.3 or greater in order to obtain the desired overall gain (Eberhardt 1981). The gain of each "stage" is related to the average secondary electron yield of the reduced lead oxide glass and, ultimately, to the work function of that surface. The lifetime of an MCP is related to the length of time that this surface, under electron and ion bombardment, can sustain its secondary emission characteristics. From this point of view, the surface deposition of a high work function material, such as carbon, is disastrous. Long chain hydrocarbons, such as pump oil and soft epoxy components, will break down (fractionate) under electron or ion bombardment (the average energy gain per stage is ~ 40 eV, sufficient to break chemical bonds) leaving primarily carbon on the glass surface thereby reducing its electron emissive properties. It is thought that small hydrocarbon molecules such as alcohol, trichlor and similar solvents are easily desorbed in their entirety from the surface without leaving a carbon residue. The breakdown of large hydrocarbon molecules to carbon deposits is probably irreversible. The process is proportional to both the quantity of heavy hydrocarbons on the surface and to the total current passing through the MCP. Thus it is reasonable to expect that the third plate in an MCP stack will be most subject to degradation, and that the last sections of the channels in the third stage are most degraded of all.

On shorter time scales, when MCPs are first pumped down, they will desorb water vapor and other light molecules at a high rate. The plates are thus "gassy" and the electron multiplication cascade will cause further desorption (as will MCP heating due to the strip current caused by applied high voltage). Some ionization of this gas will occur within the MCP pores. Since many more ionization events will occur near the rear end of the MCP where electron current is highest, the spurious pulses due to outgassing will be predominantly small. If sufficient gas is present in the channels actual voltage breakdown may occur because it is not unusual to have pressure of ~ $10^{-3}$ Torr inside channels immediately after pumpdown. Thus it is important to pump out the MCP and its surroundings to a good vacuum before operation. This gassy stage of operation may account for the initial high gain of MCPs, which is observed to decrease by a factor $\geq$ 3 over the first $10^9$ ~ $10^{10}$ counts as the surfaces are cleaned up by electron and ion bombardment. After ~ $10^{10}$ pulses the gain of "good" MCPs should level off and remain relatively constant. In addition to gain stability, burned-in MCPs can also be expected to show stable pulse height resolution of FWHM $\leq$ 80% (Timothy, 1981). From the above discussion it is clear that good handling procedures and vacuum system cleanliness must be of paramount concern both before and after launch.

## 2. Bake-out and Burn-in Procedures

### 2.1 Overview

The basic idea is to first bake-out the MCPs in high vacuum (< $10^{-7}$ T) at a moderately high temperature (125°C to 150°C) for ~ 12 hours in order to desorb the MCP surfaces. Although it is questionable whether all $H_2O$ is desorbed in this process, its vapor pressure at 125° C is two orders of magnitude higher than at room temperature and significant desorption should occur. It may well be that the desorption process is limited primarily by the low conductance of individual MCP capillaries (length/diameter ~ 40). Following bake-out, cooling, and backfill with pure $N_2$, MCPs are assembled into Z-stacks for burn-in with a $Ni^{63}$ $\beta$-source. The mounting assemblies are all ceramic and metal in order to avoid any contamination. They are then subjected to a total incident flux ~ 2 x $10^{10}$ counts and, at a gain of $\geq 10^7$, a total charge output $\geq 10^{-2}$ Cb. Note that the burn-in electronic system will be required to monitor vacuum system pressure, MCP high voltage and total accumulated counts in addition to multiplier gain and FWHM. The system will be interlocked against power failure so that loss of power and vacuum pumping capability does not damage MCPs.

The counting rates suggested below are based on data for CEM's from the work of Rosenbauer and from the LANL group. It has been suggested (McComas) that the rates for MCPs should be scaled up in proportion to their strip current, which is higher than that of CEMs by a factor $\sim$ 4. We have scaled the low rate up from 5 kHz to 10 kHz, but are presently unable to raise the maximum rate above $\sim$ 50 kHz. This will be looked into.

### 2.2 Detailed Procedure

| | | |
|---|---|---|
| Day 0 | 1. | Bake out UHV system alone to > 150° for 24 hours. Check TC monitors and system controls. Back fill with pure $N_2$. (Do not repeat this step in between batches of MCPs.) |
| Day 1 (Mon) | 2. | AM: Mount individual MCPs in clean tent and install in bake-out system. Pump out overnight at < $10^{-7}$ T. |
| Day 2 (Tue) | 3. | AM: Start bake-out to 125°C. Maintain at 125°C $\pm$5°C for $\geq$ 24 hours (i.e. AM of Day 2 to PM of Day 3). |
| Day 3 (Wed) | 4. | PM: Turn off heaters and let cool over night. |
| Day 4 (Thu) | 5. | Remove MCPs and store in $N_2$ until ready to mount in MCP holders. |
| Day 4 (Thu) | 6. | Mount MCP's in holders and pump out overnight to < $10^{-7}$ T. |
| Day 5 (Fri) | 7. | AM: Start burn-in at 10 kHz count rate. Adjust $\beta$-emitter apertures to obtain 10 $\pm$ 1 kHz on all MCPS. Take all gain data at 10 kHz; first data in AM. Measure and record pulse height distribution and extract gain and FWHM data from PHD. |
| Day 6-7 (Sat - Sun) | 8. | Run at 10 kHz over weekend. |
| Day 8 (Mon) | 9. | AM: Take gain data at 10 kHz, vent with $N_2$, repump. At < $10^{-7}$ T restart burn-in at 10 kHz. Check gain and then run overnight at 10 kHz. |
| Day 9-10 (Tue - Wed) | 10. | Same as Day 8. Take gain data twice per day in AM and PM. |
| Day 11 (Thu) | 11. | AM: Take gain data, run count rate to 50 kHz (100 kHz?). PM: Take gain data, run overnight at 50 kHz. |
| Day 12 (Fri) | 12. | Take gain data in AM and PM. Continue to run at 50 kHz. |

Day 13-14 (Sat - Sun) 13. Run at 50 kHz over weekend.

Day 15 (Mon) 14. AM: Take gain data at 50 kHz and 10 kHz. Shut down system, vent to pure $N_2$.

Day 15 (Mon) 15. AM: Check system, prepare another MCP batch and repeat procedure steps 2-15.

After bake-out and burn-in, store MCPs in $N_2$ environment. Before final flight mounting check MCP gain at 10 kHz following overnight pumpdown.

### 2.3 Life-time/Materials Compatibility Test Procedure

The following procedure is based on that described by McComas and Bame (Rev. Sci. Instrum., 55, 463, 1984). The basic idea is to first burn-in a set of MCPs according to the above specifications and then to place them in a chamber with material to be tested and run the MCPs to a total of ~ $2 \times 10^{11}$ counts at a rate of ~ $10^5$ Hz (i.e. ~ 24 days at this rate). A total count rate of $2 \times 10^{11}$ corresponds to a mission average rate of 3 kHz over 2 years. Gain and FWHM measurements will be made on a daily basis throughout this period.

Day 1 1a. Mount a sample of the material to be tested inside the vacuum test volume so that a surface area $\geq$ 3 times that of the exposed instrument area is used. (In the case of the glass-filled Noryl used in the TIDE baseplate, the exposed area is ~ 150 $in^2$. Rather than use a large monolithic surface of ~ 450 $in^2$, an appropriate number of Noryl chips left from machining the baseplate will be used.)

1b. Mount two previously burned-in MCP stacks in the chamber. (Following the suggestion of McComas and Bame, the flight-type MCPs with lowest gain may be used for lifetime tests.)

Days 2-7 1c. Pump system down to $< 10^{-7}$ T and maintain at base pressure for at least 3 days. This simulates TIDE outgassing in space prior to switch-on.

Days 7-30 2. Start life test with a gain measurement at 10 kHz. Increase count rate to 100 kHz and maintain at this level. Record gain and FWHM data three times per week (e.g., Mon., Wed., Fri.).

Day 31 3. End test if total counts have reached $\geq 1.5 \times 10^{11}$. If gain drops during days 7-30 raise the MCP HV to maintain $> 1 \times 10^7$ and continue to $\geq 1.5 \times 10^{11}$ counts.